4

FEEDBACK CIRCUITS AND OSCILLATORS

Basic principles of feedback

Feedback is the process where a fraction of output energy of same device (amplifier) is fedback to its input.

Feedback signal can be either a voltage or a current. Feedback is used for reducing noise in amplifiers and making the operation of the amplifier stable.

Two types (i) Positive feedback

(ii) Negataive feedback

Positive feedback

If the feedback voltage or current is in phase with the input signal and adds to its magnitude.

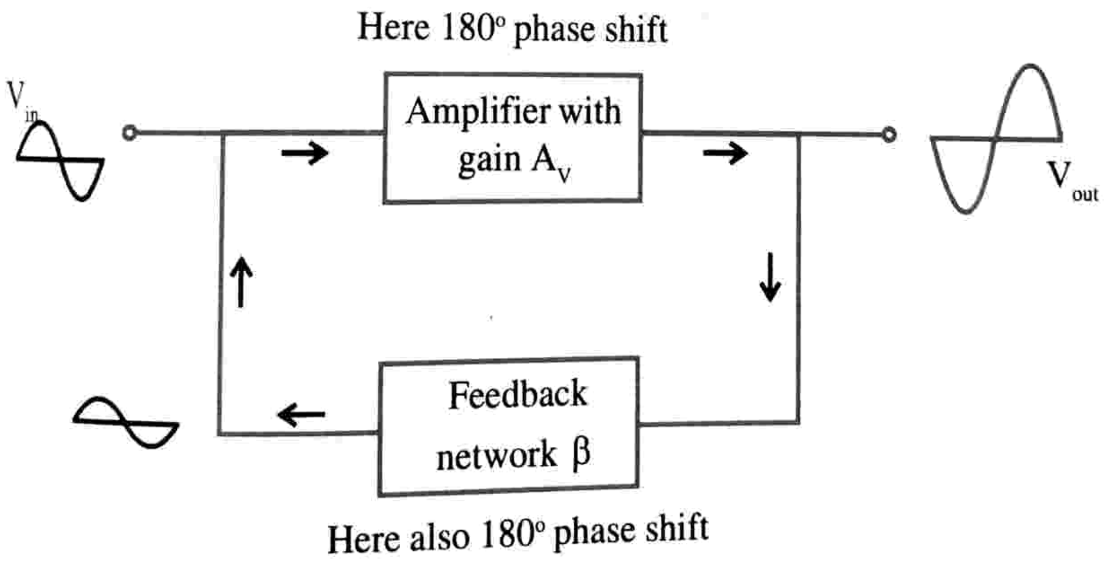

Fig. 4.1

A_V be the voltage gain of the amplifier in the absence of fedback. A portion β of the output voltage is feedback the amplifier input through the feedback network. Now the input of the amplifier becomes sum of earlier V_{in} and the feedback Voltage βV_o.

$$\therefore \text{ New gain} \quad A_V = \frac{V_o}{V_i + \beta V_o} \qquad \dots (1)$$

$$A_V(V_i + \beta V_o) = V_o$$

$$A_V V_i + A_V \beta V_o = V_o$$

$$A_V V_i = V_o - A_V \beta V_o$$

$$A_V V_i = V_o(1 - A_V \beta) \qquad \dots (2)$$

$\therefore$ Voltage gain with feedback, from (2)

$$A_{Vf} = \frac{V_o}{V_i} = \frac{\mathbf{A_V}}{\mathbf{1 - A_V \beta}}$$

Advantage

Positive feedback increases the gain of amplifier.

Disadvantage

Increased distortion and instability.

Use

In oscillators

Negative feedback (CU Nov. 2015, 2016)

If the feedback voltage or current is opposite in phase to the input signal and opposes it, the feedback is negative.

A_V be the voltage gain of the amplifier in the absence of feedback. It introduces a phase shift of 180°. But the feedback network introduces no phase shift. So the result is 180° out of phase with input V_{in}.

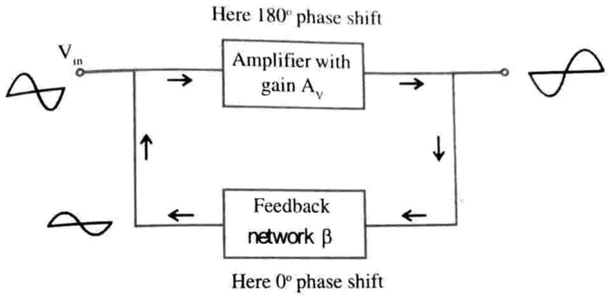

Fig. 4.2

In negative feedback, the fraction β and hence βA_V becomes negative.

$$A_V(V_i - \beta V_o) = V_o$$

$$A_V V_i = V_o + A_V \beta V_o$$

$$= V_o(1 + A_V \beta)$$

$$A_{V_f} = \frac{V_o}{V_i} = \frac{A_V}{1 + A_V \beta}$$

$\therefore$ Voltage gain with Negative feedback

$$\mathbf{A_{Vf}} = \frac{\mathbf{A_V}}{\mathbf{1 + A_V \beta}}$$

If $A_V \beta$ increases gain A_{Vf} decreases.

Note : Here the gain depends only on the feedback fraction β. So the variation in gain with frequency is totally controlled by the nature of β. If the feedback fraction is passed through a resistive network, the gain does not vary with frequency.

Example for –ve feedback

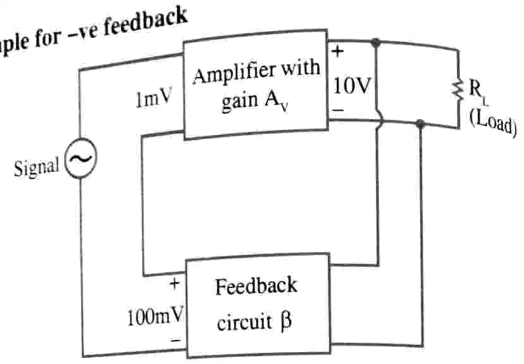

Fig. 4.3

For the amplifier

Consider $\quad V_{in} = 1mV$

$\qquad\qquad V_{out} = 10V$

Gain without feedback, $A_V = \frac{10V}{1mV} = 10{,}000$

100mV is a fraction of the output voltage V_{out} = 10V. This is fedback to the input through the fedback circuit. So new input voltage becomes 1mV + 100mV = 101mV.

Gain with feedback, $A_{vf} = \frac{10V}{101mV} = 100$ (closed loop gain)

Here $\quad \beta = \frac{100mV}{10V}$ (for feedback circuit)

$$= \frac{0.1V}{10V} = 0.01$$

Also, $A_{vf} = \frac{A_V}{1 + A_V\beta} = \frac{10{,}000}{1 + 10000 \times 0.01}$

$$= \frac{10{,}000}{1+100} = \mathbf{99.9}$$

Problems

1. *Describe the term feedback in amplifier. Explain the principle of negative feedback and discuss the advantages of negative feedback.* *(CU Nov. 2015, Nov. 2016)*

   Ans : (First two parts already described).

2. *Distinguish between positive and negative feedback amplifiers* *(CU Nov. 18)*

Advantages of negative feedback

Advantages

Less distortion in frequency, stability in gain, increased band width, improved input and output Impedances, Reduction in noise.

3. *Negative feedback is widely used in amplifier design. Why?*

   Ans : (Advantages)

(i) Gain stability

$$A_{Vf} = \frac{A_V}{1 + \beta A_V}$$

$\beta A_V >> 1$. So 1 can be neglected in the equation.

$$\therefore\ A_{Vf} = \frac{A_V}{\beta A_V} = \frac{1}{\beta}$$

i.e., the gain with negative feedback is only depending on feedback fraction β.

We know the feedback circuit is a resistive network or a voltage divider. Therefore it is not affected by changes in temperature, variations in transistor parameters and frequency. So the gain of the amplifier is stable.

(ii) Improves frequency response

We know, feedback is obtained through a resistive network. So voltage gain is not depending on frequency. i.e., voltage gain remains constant over a wide range of frequency. This improves frequency response.

(iii) Increases circuit stability

Due to variations in temperature, frequency and amplitude of signal the output of amplifier may change. So gain also may change. Due to this, distortion appears in the output. But by applying negative feedback this can be minimised. For example, due to the increase of temperature output may increase. A part of the output is fedback or brought back to the input. So the increase in amplification can be prevented. This helps the stabilization.

(iv) Increases input impedances

$$Z'_{in} = Z_{in}(1+\beta A_V) \quad \text{... (1)}$$

Here Z_{in} is the input impedence with out feedback.

Z'_{in} is the input impedance of the amplifier with negative voltage feedback. A_V is the voltage gain without feedback.

Form (1), the input impedance of the amplifier is increased by a factor $(1+\beta A_V)$

$$\beta A_V >> 1$$

$\therefore$ Z'_{in} increases considerably. As βA_V increases Z_{in} decreases. Now to the source circuit less load will be there.

(v) Decreases output impedence

$$Z'_{out} = \frac{Z_{out}}{1+A_V\beta} \quad \text{... (1)}$$

Z_{out} is the output impedance with out feedback.

Z'_{out} is the output impedance with negative voltage feedback.

From (1), output impedance is decreased by a factor $(1+\beta A_V)$.

If $\beta A_V >> 1$,

$$Z'_{out} = \frac{Z_{out}}{\beta_{A_V}}$$

i.e., Z'_{out} is lesser than Z_{out}.

i.e., Output impedance is decreased.

(vi) Reduces non-linear distortion

If D and D_{Vf} are the distortions in amplifier without and with feedback.

$$D_{Vf} = \frac{D}{1+\beta A_V}$$

$$\frac{D}{D_{Vf}} = 1+\beta A_V$$

So by applying a negative feedback, distortion can be minimized by a factor of $(1+\beta A_V)$.

Problems

4. *Write any two advantages of negative feedback* (CU Nov. 20)

Disadvantage

Reduces the gain of the amplifier.

5. *What do you mean by feedback? Explain the principle of feedback in amplifiers. Mention the advantages of negative feedback.* (CU 2017 Nov.)

Ans : *Hints:* Explanation

Principle of feedback

Advantages

Loop gain

It is the voltage gain of the forward and feedback paths. This is important in the case of design of negative feedback amplifiers. The larger the loop gain, the better, because it stabilizes the voltage gain.

6. *What is the difference between open loop gain (A_V) and closed loop gain (A_{Vf})?* (CU 2017 Nov.)

Ans : **Open loop gain** : Ratio of voltage feedback to the input voltage when the feedback network terminal connected to the input side is kept open.

Clossed loop gain : The overall gain after feedback (A_{Vf}). Amplifier and feedback circuits form a loop. When the loop is closed by connecting the feedback circuit, the gain decreases to A_{Vf}.

7. *Explain stabilization of gain.*

Ans : Due to changes in power supply voltage, or change in the parameters of the active device (transistor), the gain of the amplifier may change. Negative feedback helps to reduce this.

$$A_{Vf} = \frac{A_V}{1+\beta A_V}$$

If we make $\beta A_V >> 1$,

$$A_{Vf} = \frac{A_V}{\beta A_V} = \frac{1}{\beta}$$

So after negative feedback, the gain is independent of internal gain A_V. It depends only on feedback ratio β. We know β depends on passive elements (resistance, capacitance and inductance) of feedback network.

8. *What is the effect of negative feedback on Band width?*

Ans : With negatiave feedback BW increases. Gain decreases. But the gain – bandwidth (GBW) product remains the same.

9. *Show that* $A_{Vf} = \dfrac{A_V}{1+\beta A_V}$ *for a negative feedback amplifier. (symbols have usual meaning).*

10. *Explain the term 'Return difference'.*

Ans : If the input voltage to the amplifier is taken as unity then output voltage $(A_V \times 1) = A_V$. The feedback voltage is βA_V. So the difference between input signal and that returned by the feedback circuit is $(1-\beta A_V)$. This term is called return difference.

11. *With negative feedback to an amplifier the gain is reduced by a factor 10. By what amount will gain stability, input resistance and output resitance change?*

Ans : Gain stability and input resistance increases by 10. Output resistance decreases by 10.

12. *In high gain amplifier, negative feedback is used. Why?*

Ans : By doing this, the gain of the amplifier will not reduce too much.

13. *Give a brief account on feedback in amplifier. Also discuss about principle of negative feedback and their advantages*

(CU Nov. 19)

14. *The feedback circuits are very popular to boost the bass and treble response of an audio amplifier. Explain.*

Ans : If the feedback fraction is obtained through a resistive network, the gain of the amplifier does not vary with frequency. If we use capacitors and inductors, the feedback may be made to vary in any desired manner with frequency.

15. *What is the basic difference between feedback in biasing circuits and amplifier circuits ?*

Ans : In biasing circuits, d.c. negative feedback is used. In amplifier circuits, a.c. negative feedback is used.

Negative feedback circuits

(i) Voltage series feedback

A fraction of the output voltage (V_o) is applied in series with the input voltage (V_i) through a feedback network. Here the input to the feedback network is in parallel with the output of the amplifier.

This connection reduces the voltage gain of a feedback amplifier. But it increases the input resistance and decreases its output resistance.

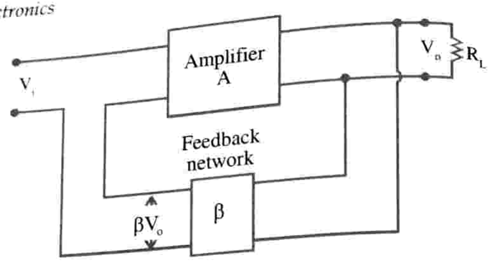

Fig. 4.4

Common collector amplifier is an example for negative voltage series feedback amplifier.

(ii) Voltage shunt feedback

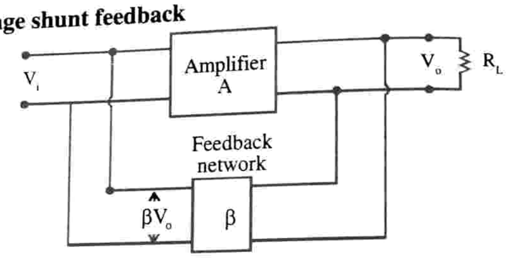

Fig. 4.5

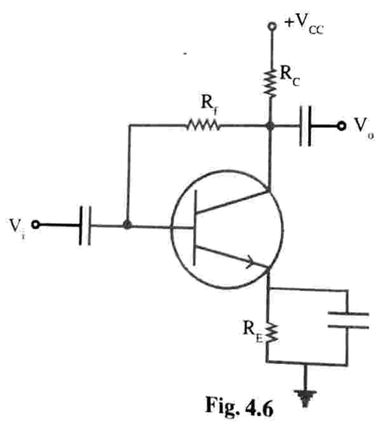

Fig. 4.6

A fraction of the output voltage is applied in parallel with the input voltage through the feedback network.

It decreases both input and output resistance of the feedback amplifier.

(iii) Current series feedback

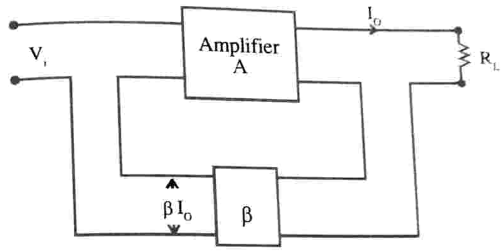

Fig. 4.7

A fraction of the output current is converted in to proportional voltage. It is applied in series with input.

It increases both input and output resistance.

(iv) Current shunt feedback

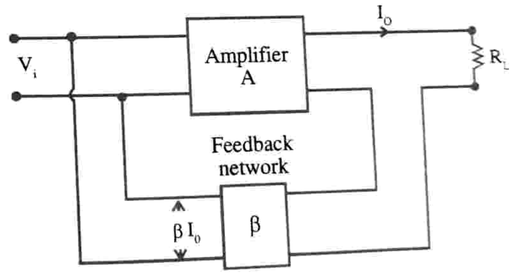

Fig. 4.8

A fraction of the output current is converted into a proportional voltage. It is applied in parallel with the input voltage.

It decreases the input resistance and increases the output resistance.

Note: In an emitter follower amplifier $\beta = 1$. So feedback percentage is 100.

Problems

16. *Explain negative feedback. Drive an expression for gain in a negative voltage feedback amplifier. What are the advantages of negative feedback?* *(CU Nov. 18)*

Hints : Explanation – Derivation for closed loop gain – Advantages (any 4)

Sinusoidal oscillator

An electronic device that generates sinusoidal oscillations of desired frequency.

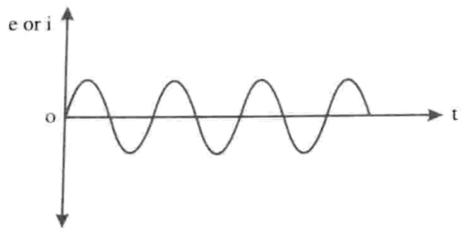

Fig. 4.9

Fig. shows an undamped sinusoidal oscillation. Here the amplitude of generated wave remains constant.

17. *The voltage gain of an amplifier without feedback is 2000. The feedback fraction is 0.01. Find the voltage gain of the amplifier if negative voltage feedback is applied.*

Ans : $A_V = 2000, \quad \beta = 0.01$

$$A_{Vf} = \frac{A_V}{1+\beta A_V} = \frac{2000}{1+0.01\times 2000} = \frac{2000}{21} = \mathbf{95.23}$$

18. *An amplifier has a voltage gain of 50. To reduce the distortion present in it, 10% negative feedback is employed. Calculate voltage gain with feedback.*

Ans : $\beta = \frac{10}{100} = 0.01$

$A_V = 50$

$$A_{Vf} = \frac{A_V}{1+\beta A_V} = \frac{50}{1+0.01\times 50} = \frac{50}{1.5} = \mathbf{33.33}$$

19. *The multistage amplifier is having an overall gain 150. The gain is reduced to 20 when negative feedback is applied. Calculate the fraction of the output that is fedback to the input.*

$A_V = 150$

$A_{Vf} = 20$

$\beta = ?$

Ans : $A_{Vf} = \frac{A_V}{1+\beta A_V}$

$$20 = \frac{150}{1+\beta\times 150}$$

$$1+\beta\times 150 = \frac{150}{20} = 7.5$$

$$150\beta = 6.5$$

$$\beta = \frac{6.5}{150} = \mathbf{0.04}.$$

20. *The open loop gain of an amplifier is 10000. A negative feedback of 10db is applied to it. Find the voltage gain with feedback and feedback ratio β ?*

Ans : **With out feedback**

dB voltage gain $= 20\log_{10} 10000$

$= 20\log_{10} 10^4$

$= \mathbf{80}$ db

With feedback

$$\text{dB voltage gain} = 80 - 10 = 70\text{db}$$

i.e., $20\log_{10}(A_{Vf}) = 70$

$$\log_{10}(A_{Vf}) = \frac{70}{20} = 3.5$$

$\therefore$ A_{Vf} = Antilog 3.5 = **3162**

To find β

$$A_{Vf} = \frac{A_V}{1+\beta A_V}$$

$$3162 = \frac{10000}{1+\beta\times 10000}$$

$$1 + 10000\,\beta = \frac{10000}{3162} = 3.1626$$

$$10000\beta = 2.1626$$

$$\beta = \mathbf{2.16 \times 10^{-4}}$$

21. *The gain of an amplifier without feedback is 500. It is used in a negative feedback loop with feedback ratio 0.01. Due to temperature, the gain without feedback changes by 20%. What would be the corresponding change in gain with feedback? Calculate the gain with feedback.*

Ans : $A_V = 500$

$\beta = 0.01$

$$A_{Vf} = \frac{A_V}{1+\beta A_V} = \frac{500}{1+500\times 0.01} = 83.3$$

Percentage change in gain with feedback

$$\frac{\text{Change in } A_{Vf}}{A_{Vf}}\times 100 = \frac{\text{Change in } A_V}{A_V}\times\frac{1\times 100}{1+\beta A_V}$$

$$= 20\times\frac{1}{1+500\times 0.01} = \mathbf{3.3\%}$$

22. *Voltage gain of an amplifier without feedback is 3,000. (i) Calculate the closed loop gain with negative feedback of feedback fraction 0.01. (ii) Also find the closed loop gain when the open loop gain increases to 50%.* *(CU 2017 Nov.)*

Ans : (i) $A_{OL} = 3000,\ \beta = 0.01$

$$A_{CL} = \frac{A_{OL}}{1+\beta A} = \frac{3000}{1+0.01\times 3000} = \mathbf{96.77}$$

(ii) $A_{CL} = 3000 + 1500 = 4500$

$$A_{CL} = \frac{A_{OL}}{1+\beta A} = \frac{4500}{1+0.01\times 4500} = \mathbf{97.82}$$

23. *An amplifier has an open loop gain of 800 and a feed back fraction of 0.05. If the open loop gain changes by 20% due to temperature find the percentage of change in closed loop gain* *(CU Nov. 20)*

24. *In a negative feedback amplifier, A = 100, β=0.04 and V_i = 50mV. Find a) Gain with feedback b) Output voltage c) Feedback factor d) Feedback voltage* *(CU Nov. 18)*

Ans: a) $A_{Vf} = \frac{A_V}{1+\beta A_V} = 20$

b) $V_o = A_{Vf}\cdot V_i = 1\text{V}$

c) Feedback factor = $\beta A_V = 4$

d) Feedback voltage = $\beta V_o = 0.04\text{V}$

Oscillatory circuit

A circuit which produces electrical oscillations of any desired frequency.

Tank circuit

It is the simplest type of electrical oscillatory circuit. An inductor L and a capacitor C connected in parallel form a tuned or tank circuit. Here both are capable of storing energy. Capacitor stores energy in its electric field whenever there is potential difference across its plates. An inductor coil stores energy in its magnetic field when ever current flows through it.

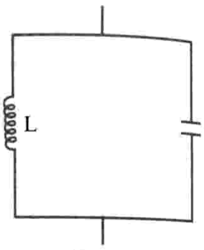

Fig. 4.10

At first the capacitor C is charged from a dc source. The upper plate B has deficit of electrons and lower plate A has excess of electrons. ∴ There is a voltage across capacitor. Now capacitor has electrostatic energy.

When switch S is closed (in fig. 4.12), electrons move from plate A to B through coil L. Capacitor discharges through inductance. The current flow set up magnetic field around the coil. Due to the effect of inductance current grows and becomes maximum. When capacitor is fully discharged current become maximum. At this stage the electrostatic energy across the capacitor is fully converted in to magnetic field energy around the coil.

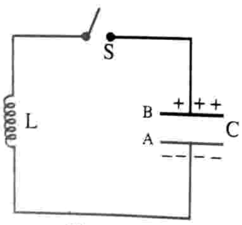

Fig. 4.11

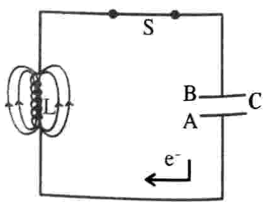

Fig. 4.12

Once the capacitor is discharged, the magnetic field in L will begin to collapse. This produces a counter e.m.f. According to Lenz's law, this counter e.m.f. keeps the electrons moving the same direction. i.e., more electrons are transformed to the plate B than A. Hence the capacitor becomes charged with opposite polarity. So plate B become –ve and plate A +ve.

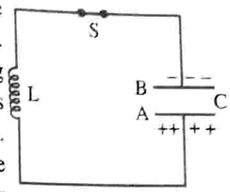

Fig. 4.13

Now e⁻s flow in opposite direction and magnetic field is produced in opposite direction.

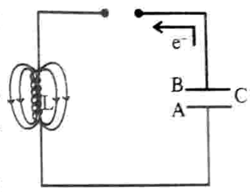

Fig. 4.14

The sequence of charging and discharging continues. This results in alternating motion of electrons. It produces oscillating current. The energy is alternately stored in the electric field of the capacitor and the magnetic field of the inductor.

Note : In a practical tank circuit resistive and radiation losses in coils and dielectric losses in capacitor are there. So a part of energy is lost in each cycle. So the oscillation becomes **damped**.

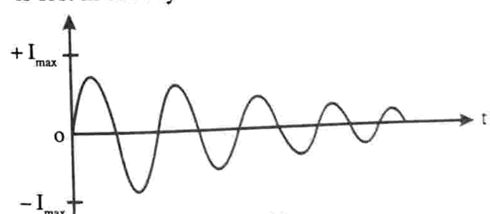

Fig. 4.15

The frequency of oscillation in a tank circuit is

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where L is the inductance and C is the capacitance.

Barkhausen criterion (CU Nov. 2016, 2017)

In order to produce continuous undamped oscillations at the output of an amplifier, the positive feedback should be such that

$$\boxed{\beta A_V = 1}$$

L.C. Oscillators (CU Nov. 15)

Frequency of LC oscillator is from less than 1 to over 500 MHz. The active device may be a transistor or a FET. In addition to active devices, an LC resonant circuit is used to feedback a signal of correct amplitude and phase. Under this condition the oscillators will be sustained (not damped).

LC oscillators based on the principle of feedback have three features —

(i) They must contain an active device (transistor) which works as an amplifier.

(ii) There must be a feedback network which provides +ve feedback. i.e., it introduces a phase shift of 180° so that total phase shift between output and input is zero or integral multiple of 2π.

(iii) The amount of feedback must be +ve and sufficient to overcome the losses.

Different types of transistor oscillations

Tuned collector oscillator

Tuned (tank) L.C. circuit L_1C_1 is connected in the collector branch. R_1, R_2, R_E perform the proper d.c. operating conditions. C_E is the emitter by-pass capacitor. C provides low reactance path to the oscillations.

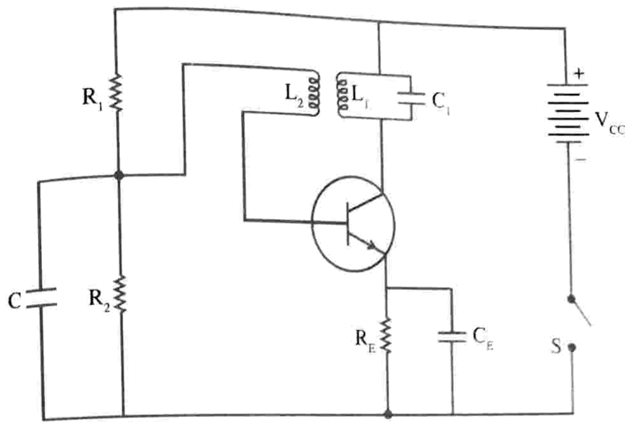

Fig. 4.16

Frequency of oscillation $f = \dfrac{1}{2\pi\sqrt{L_1C_1}}$.

Problem

25. *With a neat diagram explain the working of a tuned collector oscillator.* *(CU Nov. 20)*

Colpitt's oscillator

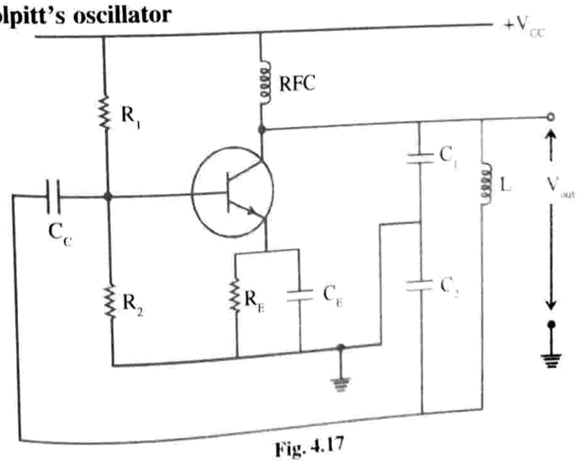

Fig. 4.17

Here two capacitors C_1 and C_2 are placed across a common inductance L. The centre of two capacitors is tapped and earthed. C_1, C_2, L form the tank circuit. RFC is the Radio Frequency Choke (inductance)

Frequency of oscillation $f = \dfrac{1}{2\pi\sqrt{LC_{effective}}}$

where $C_{effective} = \dfrac{C_1C_2}{C_1+C_2}$

Working

When power is on, the capacitors C_1 and C_2 are charged. They discharge through L. Oscillations are set. The oscillations across C_2 are applied to the emitter- Base junction of transistor. Transistor works as an amplifier for this input. Amplified form of it is obtained in the collector circuit.

Capacitors C_1 & C_2 form the voltage divider and used for providing the feedback voltage. C_C acts as the device for the feedback voltage to the tank circuit. C_C blocks d.c. voltage from reaching the base of the transistor. Transistor produces a phase shift of 180°. Capacitive feedback produces another feedback of 180°. So total phase shift is 360° or 0°. So the feedback is +ve. This is helpful for oscillations.

When V_{CC} is switched on, C_1 & C_2 are charged and discharged through L. Oscillations are produced. Due to feedback these oscillations become sustained. By changing C_1 & C_2 frequency of oscillation can be varied.

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{L\left(\dfrac{C_1C_2}{C_1+C_2}\right)}}$$

Feedback fraction

$$\beta = \frac{V_f}{V_{out}} = \frac{X_{C_2}}{X_{C_1}}$$

$$\frac{\dfrac{1}{\omega C_2}}{\dfrac{1}{\omega C_1}} = \frac{C_1}{C_2}$$

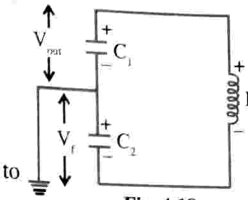

Fig. 4.18

Use : as signal generators (from 1MHz to 500MHz).

Problems

26. *With a neat diagram, explain the working of a colpitt's collector oscillator and derive the expression for frequency. (CU Nov. 18)*

Hints : Circuit diagram - explanation - expression for frequency.

27. *The capacitors used in a 10MHz colpitts oscillator are* $C_1 = 1000\,pF$ *and* $C_2 = 10pF$. *Find the value of inductance used.*

Ans : In colpitt's oscillator capacitors are in series.

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{C_1+C_2}{C_1C_2}$$

$$C = \frac{C_1C_2}{C_1+C_2} = \frac{1000\times10}{1000+10} = \frac{10000}{1010} = 9.9pF = 9.9 \times 10^{-12}F$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$f^2 = \frac{1}{4\pi^2LC}$$

$$L = \frac{1}{4\pi^2f^2C} = \frac{1}{4\times(3.14)^2\times(10\times10^6)^2\times9.9\times10^{-12}}$$

$$= \frac{1}{4\times9.86\times10^{14}\times9.9\times10^{-12}} = \frac{1}{390.456\times10^2}$$

$$= 0.00256\times10^{-2} = 0.0000256H$$

$$= 0.0256mH$$

Hartley oscillator

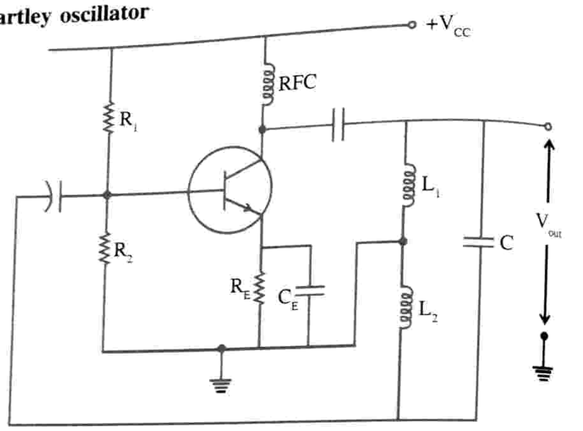

Fig. 4.19

Here two inductors L_1 and L_2 are placed across a common capacitor C. The centre of two inductors is tapped and earthed. L_1, L_2 and C form the tank circuit.

Frequency of oscillations $f = \frac{1}{2\pi\sqrt{LC}}$

Where $L = L_1 + L_2 + 2M$

M is the mutual inductance between L_1 and L_2.

Working

C is charged. When it is fully charged, it discharges through L_1 and L_2. Oscillations are set up. Out put voltage appears across L_1. Feedback voltage across L_2. Voltage across L_2 provides +ve feedback. A phase shift of 180° is obtained by transistor. Another phase shift of 180° is obtained by L_1–L_2 voltage divider. Total feedback 360° or 0°. This helps for oscillation.

Feedback fraction

$$\beta = \frac{V_f}{V_{out}} = \frac{X_{L_2}}{X_{L_1}}$$

$$= \frac{\omega L_2}{\omega L_1}$$

$$\beta = \frac{L_2}{L_1}$$

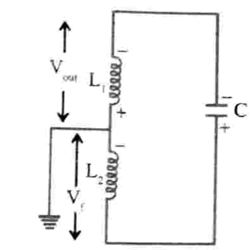

Fig. 4.20

Problems

28. *Briefly explain the working of a Hartlley oscillator.*

(CU Nov. 19)

29. *The frequency of a Hartley oscillator is 1000kHz. If the capacitance of the capacitor used is 20pF. Calculate the inductance. The two series of the split inductances are in the ratio 2:1. Calculate each inductance.*

Ans : f = 1000kHz C = 20pF, $L_1 : L_2 = 2:1$

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \therefore f^2 = \frac{1}{4\pi^2 LC}$$

$$L = \frac{1}{4\pi^2 C f^2} = \frac{1}{4\times(3.14)^2\times 20\times10^{-12}\times(10^6)^2}$$

$$= \frac{1}{4\times 9.8596\times 20} = \frac{1}{788.768} = 0.00126780$$

Given $L_1 = L_2 = 2:1$

$L_1 = 2L_2$

$L_1 + L_2 = L = 0.00126780$ (M is neglected)

$2L_2 + L_2 = 0.0012678$

$3L_2 = 0.001268$

$L_2 = 0.0004H$

$= 0.4mH$

$\therefore \quad L_1 = \mathbf{0.8}mH$

30. *Find the operating frequency of a Hartley oscillator if L_1 = $100\,\mu H$, L_2= $1mH$, mutual inductance between the coils M = 20μH and C = 20pF.* (CU Nov. 2015)

Ans : $L = L_1 + L_2 + 2M$

$= 100 \times 10^{-6} + 1 \times 10^{-3} + 2 \times 20 \times 10^{-6}$

$= 140.001 \times 10^{-6}H$

$C = 20 \times 10^{-12}F$

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{140.001\times10^{-6}\times20\times10^{-12}}}$$

$$= \frac{1}{2\pi\sqrt{2800\times10^{-18}}} = \frac{1}{2\times3.14\times52.915\times10^{-9}}$$

$$= \frac{1}{332.3062\times10^{-9}} = 0.003\times10^{9}$$

$= 3\times10^{6}\,Hz = \mathbf{3MHz}$

31. *What are the drawbacks of oscillator circuits using L-C elements?*

Ans : (i) They suffer from frequency instability and poor wave form.

(ii) They can not be used for very low frequencies. Because they become too much bulky and expensive.

R – C (or) Phase shift circuit

Phase shift or R – C oscillators can be used for very low frequencies. Here first 180° phase shift is produced by a phase shift circuit. Another 180° phase shift is produced due to the transistor properties.

Here an R – C network is used. Fig. shows an R – C network. Alternating voltage V_1 is applied across R. The network produces a phase change of ϕ. If R is varied, ϕ also changes.

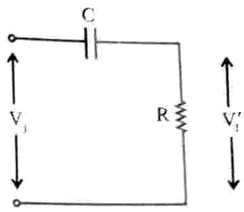

Fig. 4.21

If R = 0, V_1' will lead V_1 by 90°. Here ϕ = 90°. But R = 0 is an ideal condition. Always R is present. So we put ϕ = 60° instead of ϕ = 90°.

So to produce a phase shift of 180°, three RC networks are needed.

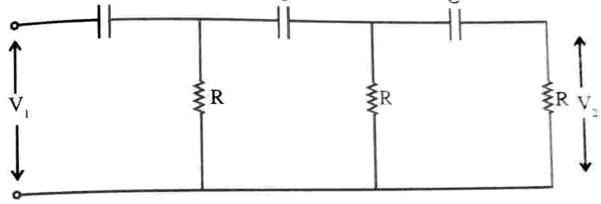

Fig. 4.22

Each RC network produce a phase shift of 60°.

Phase shift oscillator

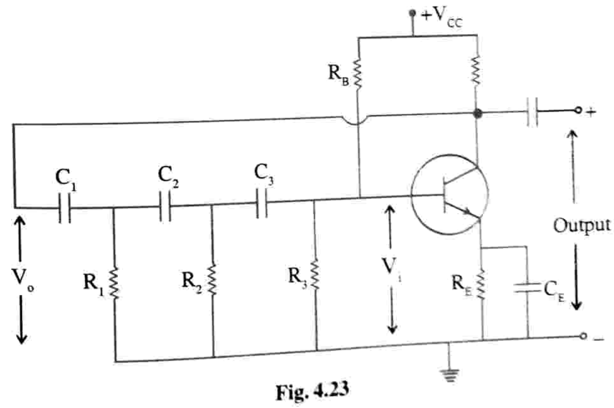

Fig. 4.23

Fig. consists of three R – C networks and a single transistor amplifier. The phase shift in each RC is 60°. So total phase shift (in R_1C_1, R_2C_2 and R_3C_3) is 180°. The frequency of oscillation,

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

Here $R_1 = R_2 = R_3 = R$ and

$C_1 = C_2 = C_3 = C$

The output V_o of the amplifier is fedback to RC feedback network V_i appears at the output of feedback network. V_i is applied to the transistor amplifier.

Feedback fraction $\beta = \frac{V_i}{V_o}$

Problem

32. With a neat diagram explain the working of a phase shift oscillator *(CU Nov. 17)*

Advantages

1. Transformers or inductors are not used.
2. To produce very low frequencies, it can be used.
3. Good frequency stability is provided.

Disadvantage

1. Feedback is very small.
2. Output is small.

32. A phase shift oscillator uses 5pF capacitors. Find the value of R to produce a frequency of 800kHz. *(CU Nov. 20)*

Exercises

1. Draw the circuit diagram of a phase shift oscillator with labels on the components. Give the expression for its frequency. (CU Nov. 16)
2. Distinguish between LC and RC oscillators (CU Nov. 15)

3. Describe the construction and working of an RC phase shift oscillator. Obtain the expression for frequency.

Ans : (First part already described)

To find frequency

Ans : *Hints*

$$\alpha R = X_C$$

$$\alpha = \frac{1}{\omega CR}$$

The phase shift of β is 180° for $\alpha^2 = 6$

$$\therefore \quad \sqrt{6} = \frac{1}{\omega CR}$$

$$\sqrt{6} = \frac{1}{2\pi fCR}$$

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

4. Design a phase shift oscillator to have a frequency of 1kHz. (CU Nov. 15)

Ans : To find R and C, we first choose C because, only specified values of capacitors are available.

Choose $C = 0.01\,\mu F$

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

$$f = 1kHz,\ C = 0.01\,\mu F$$

$$\therefore \quad R = \frac{1}{2\pi fC\sqrt{6}}$$

$$= \frac{1}{2\times 3.14\times 1\times 10^3\times 0.01\times 10^{-6}\times\sqrt{6}}$$

$$= \frac{1}{6.28 \times 2.449 \times 0.01 \times 10^{-3}} = \frac{10^3}{0.1538} = 6.5 \times 10^3$$

$$= \mathbf{6.5 k\Omega}$$

5. What is the difference between an oscillator and an amplifier?

Ans : Oscillator is an amplifier with positive feedback.

If A_V is the gain and β is the feedback fraction,

$\beta A_V = 1$

6. For low frequency applications we use RC oscillators and not LC oscillators. Why?

Ans : At high frequencies (> 100 kHz) we use LC oscillators. At these frequencies, the physical size of circuit elements are very small.

At low frequencies (1Hz to 100kHz), the size of LC resonant circuit elements becomes very larger. ∴ RC type is used.

7. What are the limitations of LC and RC oscillators?

There operating frequency does not remain constant. As the ckt. operates, it will warm up. The values of inductors and resistors will change with temperature. So frequency changes.

If we change any component in the feedback network, frequency will change. To keep the frequency constant, piezo electric crystals are to be used in place of LC and RC networks.

Piezo electric crystals

When we apply an a.c., voltage across certain crystalline materials (quartz, tourmaline, Rochelle salt etc.), they vibrate with the same frequency of applied voltage.

Conversely when these crystals are placed under mechanical strain (or compressed), or made to vibrate, an a.c. voltage is formed. This effect is known as **piezo electric effect**. Such crystals are called piezo electric crystals.

Working of Quartz crystal

Quartz crystal is placed between two metal plates. This arrangement behaves like a capacitor with crystal as the dielectric. If

we apply an a.c. voltage across this crystal, it will vibrate with the same frequency of applied voltage. Crystal is having a natural frequency of vibration. If the frequency of applied voltage is made equal to this, crystal vibrations become maximum.

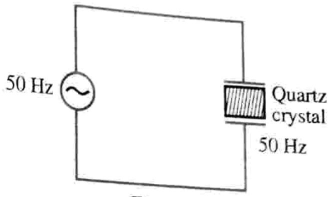

Fig. 4.24

For quartz crystal accuracy and stability of the oscillation frequency are important.

The crystal acts like a large inductor in series with a small capacitor. Due to this the resonant frequency is totally unaffected by transistor and stray capacitances.

They work well up to 10MHz on the fundamental frequency. For generation of higher frequencies, a crystal can be used to vibrate on overtones. By doing this we can reach upto 100MHz.

Equivalent circuit of crystal

If the crystal is not vibrating, it is simply equal to **Mounting capacitance** C_m. Now it has two metal plates with a dielectric in between the two.

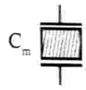

Fig. 4.25

When crystal vibrates, it is equivalent to R – L – C – series circuit.

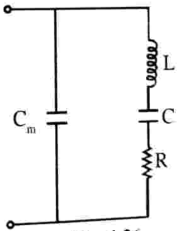

Fig. 4.26

$$\text{Q factor of crystal} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Frequency response of crystal

The series resonance frequency of the crystal

$$f_s = \frac{1}{2\pi\sqrt{LC}}$$

The changes in supply voltage, transistor parameters etc. will not affect this frequency. So frequency stability of crystal oscillator is very high.

Transistor crystal oscillator

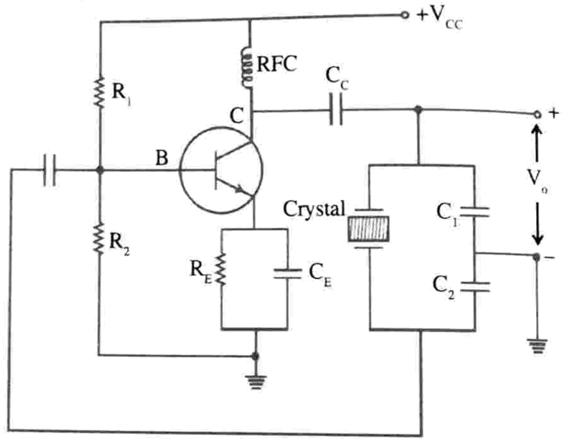

Fig. 4.27

The resistors R_1, R_2 and R_E provide a stabilised dc bias. C_E bypasses R_E. RFC coil provides dc collector load and also prevents any ac signal from entering the dc supply. C_C is the coupling capacitor. It blocks any dc between collector and base. It has negligible reactance (X_C). The crystal is excited in the series resonant mode. Because it is connected as a series element in the feedback path from collector to the base. Feedback is +ve. A phase shift of 180° is produced by the transistor. A further phase shift of 180° is provided by the capacitor voltage divider.

Advantage

1. It is a fixed frequency oscillator.
2. High order of frequency stability.
3. Q-factor of crystal is very high.

Disadvantage

1. For each desired frequency, separate crystal must be used.
2. It can be used only in low power circuits.
3. Frequency can not be changed or varied.

Exercise

8. What is parallel resonant frequency of crystal oscillator?

   Ans : It is the frequency at which the vibrating crystal behaves as a parallel - resonant circuit.

   At a slightly higher frequency the resultant reactance of R – L – C – branch becomes inductive and becomes equal to X_{C_m}. The crystal now acts as parallel resonance circuit.

$$f_p = \frac{1}{2\pi\sqrt{LC_T}}$$

where $\frac{1}{C_T} = \frac{1}{C} + \frac{1}{C_m}$

9. Distinguish between oscillators and amplifiers? (CU Nov. 15)
10. Distinguish between LC and RC oscillators (CU Nov. 15)
11. Define Q or Quality factor.

    Ans : The reactive energy of a coil is determined by X_L. The coil's dessipated energy is determined by the series resistance R_S of the coil winding. Q is determined by the ratio of $\frac{X_L}{R_S}$

Problem

33. *Calculate the series resonant frequency (f_s) and parallel resonant frequency (f_p) of a crystal oscillator in which $L = 2H$, $C = 0.02pF$, $R = 500\Omega$ and $C_m = 10pF$.*

Ans : $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{2\times 0.02\times 10^{-12}}}$

$= \frac{1}{2\times 3.14\times 0.2\times 10^{-6}}$

$= \frac{10^6}{1.256} = 0.8\times 10^6\,\text{Hz} = 800\text{kHz}$.

$C_T = \frac{C\times C_m}{C+C_m} = \frac{0.02\times 10}{0.02+10} = \frac{0.2}{10.02}$

$= 0.01996\,\text{pF} = 0.01996\times 10^{-12}\text{F} = 1.996\times 10^{-14}\text{F}$

$f_p = \frac{1}{2\pi\sqrt{LC_T}} = \frac{1}{2\times 3.14\sqrt{2\times 1.996\times 10^{-14}}}$

$= \frac{1}{2\times 3.14\times 0.1997\times 10^{-6}}$

$= \frac{10^6}{1.254} = 0.7974\times 10^6$

$=$ **797**kHz.

Assignments

1. Give the difference between closed loop gain and open loop gain.

   (The quantity βA is called open loop gain. It is the amount of feedback voltage when the input signal voltage is unity.)

2. How is a feedback introduced in CE amplifier?

3. How stability and bandwidth of an amplifier increases by using negative feedback?

4. Give an example for a negative voltage series feedback amplifier.

   Ans: C C amplifier.

5. Why negative feedback factor is a negative number, when expressed in dB?

   Ans: Feedback is $\frac{A_f}{A}$.

   In dB, feedback is $20\log\frac{A_f}{A}$

   For –ve feedback it is $= 20\log\frac{1}{1+\beta A}$

   $= -20\log(1+\beta A)$

6. The voltage gain of an amplifier is 50. A negative feedback of 10% is applied to it. Find voltage gain with feedback. Also calculate the voltage gain when feedback ratio is halved.

   (Ans: 8.3, 14.3)

7. The voltage gain of an amplifier with bandwidth of 200 kHz is 40dB. If 5% negative feedback is applied, calculate its new bandwidth?

   (Ans: 1.2 MHz)

8. The feedback ratio of an amplifier is 5%. The open loop gain of this negative feedback amplifier is – 99. Find the gain of the above amplifier before and after feedback.

   (Ans: 1980, 19.8)